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WEATHER EFFECTS IN SELECTED AIR WARFARE SIMULATIONS

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13. ABSTRACT *(Maximum 200 words)*
This report describes the results of a limited review of some of the literature on weather effects on electro-optical weapon systems, and how selected military models account for these effects. THUNDER simulates a conventional campaign that emphasizes the air war and accounts for the effects of ceiling and visibility on the air war. The Extended Air Defense Simulation (EADSIM) ignores weather effects. When executed at high resolution, THUNDER simulates some of the effects of weather on the air war, especially air-to-ground attack missions. Weather forecasts of ceiling and visibility affect mission planning and arming of aircraft; "actual" ceiling and visibility affect the use of airbases and the probability of target acquisition, discrimination and kill. The only weather factors explicitly allowed are ceiling and visibility, both of which are user-provided. The user controls all input, including weather and probabilities, through formatted data files. THUNDER's approach to weather effects should be validated. For example, the goodness of probabilities of success of various portions of an attack mission affected by weather (e.g. Are probability models physics-based?), the realism of other weather-related user input, and the degree of THUNDER's sensitivity to weather input needs to be determined. Other conclusions and recommendations are provided.

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LIST OF ACRONYMS

AGM	air-to-ground missile
ATO	air tasking order
C^2	command and control
C^3I	command, control, communications, and intelligence
CFLOSA	cloud-free line-of-sight aloft
E^2DIS	Environmental Effects for Distributed Interactive Simulation
EADSIM	Extended Air Defense Simulation
EM	electromagnetic
EO	electro-optical
ID	identification
IR	infrared
JMEM	Joint Munitions Effectiveness Manual
MMW	millimeter wave
PGM	precision guided munition
PL/GPAA	Phillips Laboratory Geophysics Directorate, Atmospheric Structures Branch
PL/GP-M	Phillips Laboratory Geophysics Directorate, Modeling and Simulation
TAS	target acquisition system
TDA	Tactical Decision Aid

FOREWORD

Science and Technology Corporation (STC) is pleased to submit this report "Weather Effects in Selected Air Warfare Simulations," written by Mr. John Burgeson of the STC Nashua, New Hampshire office. The work was performed for Phillips Laboratory Geophysics Directorate, Hanscom Air Force Base, Massachusetts, under Contract No. F19628–95–C–0005 entitled "Development, Implementation, and Analysis of an Environmental Simulation Information Reference Library and Archive (ESIRLA)." The author wishes to extend his thanks to Lt. Col. Frank Zawada, Phillips Laboratory Geophysics Directorate, Modeling and Simulation, for funding the literature research and providing access to needed documentation.

1. INTRODUCTION

This report summarizes the results of the research of the 13 referenced documents. The review focused on two analytical models: THUNDER, a simulation of a conventional campaign that emphasizes the air war, and the Extended Air Defense Simulation (EADSIM), which models air and missile warfare. Both models are discussed, but the review is not intended to be comprehensive. The purpose of the review is to identify the weather factors and weather effects included in these models, to describe how they are incorporated in the models, and to determine the impact of using weather on the results of the simulation. The specific weather effects (that is, the effects the natural environment has on system performance) on both simulated weapon systems and electro-optical weapon systems are described, as well as the weather factors needed to determine these effects. The reports concludes with a discussion on how the incorporation of weather effects could be improved (or included) and how this might be accomplished.

2. THUNDER (References 1 and 2)

THUNDER is a two-sided (red and blue) model designed to simulate a conventional, theater level war. Although primarily an air combat model, it also simulates ground combat based on the Army's Concepts Evaluation Model. THUNDER can simulate a conventional war anywhere an adequate database (e.g., terrain, weather) exists by stochastically modeling the mission planning sequence for explicit air missions and the execution of those missions. Aircraft are allocated based on current resources, target priorities, and air apportionment orders. The aircraft allocation process assigns aircraft to targets and generates air tasking orders (ATO). The air mission includes airbase operations, surface-to-air attacks, and air-to-surface attacks.

2.1 WEATHER IMPACTS

The THUNDER model incorporates some of the effects of weather (in THUNDER ceiling and visibility are weather) on air missions where it impacts airbase operations, air-to-ground target acquisition, target discrimination, and weapon effectiveness. Weather effects are described in detail in Sections 2.4–2.7. "*Forecasts*" of ceiling and visibility are used in mission planning, and the "*actual*" ceiling and visibility affects mission execution and its success. The quotation marks point out that *forecast* and *actual* weather are not real but are prescribed by the user.

THUNDER, a flexible, highly data-dependent model, has multiple levels of resolution in seven major areas. Resolution is determined in the user-input data file **control.dat**, described in Appendix A1. At low resolution, the weather is always perfect (ceiling and visibility are infinite) and thus has no impact. At high resolution the weather impacts are controlled by the user, who inputs both the *actual* weather used by

THUNDER to model aircraft operations and the weather *forecasts* used to plan missions (this input data file, **weather.dat**, is discussed in Section 2.3 and in greater detail in Appendix A.5). THUNDER is designed such that nearly all data are stored in a database; data are not part of the model but are stored in the form of data files, several of which are examined in Appendix A.

2.2 WEATHER FACTORS

By using ceiling and visibility (and only these weather factors) in **weather.dat**, THUNDER accounts for several weather effects on the air war. At high resolution the user specifies the *forecasts* of ceiling and visibility used in planning air missions, and the user prescribes the ceiling and visibility (i.e., the *actual* weather data) used in modeling the execution of the missions. *Forecasts* of ceiling and visibility affect mission planning, for example, "*inaccurate forecasts*" of bad weather could ground aircraft that should have been committed to battle. (The user also prescribes accuracy when specifying the weather scripts.) *Actual* weather directly affects air operations, for example, bad weather can prevent a target from being found or target specific elements from being identified. At low resolution, however, THUNDER assumes perfect weather (ceiling and visibility unrestricted); weather in not a factor.

2.3 WEATHER INPUT

For high resolution modeling, the user controls the weather's impact on planning and air operations through the weather data file, whose data typically comes from historical data or simulations, and through other THUNDER input data files that provide the effects of weather. The layout of these files is presented in complete detail in Appendix A to illustrate how weather effects are incorporated into THUNDER.

The weather data file, **weather.dat** (see Appendix A.5 for details), has a set of stations (points within the battle space, not necessarily weather observing stations), each with a name, identification number, and latitude. The file also defines weather bands and has a table dividing the day into time segments. Weather bands are categories of ceilings and visibilities, for example, 500 feet and 3 nautical miles. Stations and time segments are used in two weather scripts, which are large tables: one containing the *actual* ceilings and visibilities for each station, day, and day segment; the other containing the *forecasts* of ceilings and visibilities for each station, day, and day segment.

Some input tables (for example, **tgtacq.dat**, described in Appendix A.3) use a weather band as an argument rather than numerical ceilings and visibilities. A look-up table in **weather.dat** defines band numbers in terms of sets of ceiling and visibility minimums. When resolution is high, a ceiling and visibility

from one of the scripts is used to look up the weather band number in the table. When the resolution is low, the highest of these bands is used as a table argument.

2.4 WEATHER EFFECTS ON MISSION PLANNING

THUNDER accounts for the weather *forecast* only during the process of planning air missions and arming an aircraft. Aircraft perform different missions with different weapon configurations and with different degrees of effectiveness. Linear programming is used to maximize mission effectiveness when assigning missions to air squadrons and assigning the squadron's sorties to targets. The expected effectiveness of the aircraft load, which is part of the process of selecting the configuration of the aircraft-weapon system that will fly against a target, is a function of the "*predicted*" ceiling and visibility at the target as well as other factors. This is the only use made of target weather *forecasts*.

Weapon effectiveness is input into THUNDER through data tables (such as **airgrdpk.dat**, discussed in Appendix A.2) that yield the effectiveness of air-to-ground weapons against a set of standard targets (contained in the data file **stdtgt.dat**) as a function of weather band, side (blue or red), aircraft type, and munition type. THUNDER uses weapon effectiveness tables twice, first for mission planning and then for aircraft arming before the mission is flown, each case accounting for the weather *forecast*. (Clearly, these tables are critical to a successful simulation of weather effects.) The most effective weapon configuration is selected by linear programming from those available at the time of aircraft arming; accordingly, the selected configuration may be different from the one planned.

2.5 WEATHER EFFECTS ON MISSION EXECUTION

The purpose of air-to-ground missions is to find and destroy specific targets. The aircraft group must first fly to the target area and in many cases the weapon systems must acquire the specific targets (one or more depending upon the number and type of weapons carried by the aircraft). The *actual* weather (i.e., ceiling and visibility) first affects the acquisition process through the air-to-ground weapon minimums data file, **agwpnmin.dat** (see Appendix A.4), which specifies the minimum ceiling and visibility for each valid type air-to-ground munitions-aircraft combination.

Weather also affects target discrimination, weapon effectiveness, and base operations. For example, an aircraft must be able to distinguish among targets; THUNDER accounts for weather's effects by providing the probability of discrimination in data file **tgtacq.dat**. This probability is used with weather and perception level (a value assigned to describe the intelligence of enemy targets) in target discrimination analysis. After

the aircraft has found and the weapon system has acquired its target, THUNDER uses the *actual* ceiling and visibility (scripted in data file **weather.dat**) at the target to determine the probability of killing the target as specified in data file **airgrdpk.dat**. Finally, each airbase listed in data file **airbase.dat** has a specified minimum operational ceiling and visibility. If the *actual* ceiling and visibility (the *forecast* is irrelevant) is below minimums for that base, the aircraft flight will land at a dispersal base or the nearest friendly base.

2.5.1 GROUND TARGET ACQUISITION

Weather enters the mission execution process through user-input aircraft acquisition tables and target acquisition tables. The maximum target detection range, and the minimum ceiling and visibility required for detection by each fighter-bomber aircraft type and target type are user input in the data file **typeac.dat** (see Appendix A.6). When the aircraft group reaches a target area, *actual* weather from **weather.dat** is used to determine if the target can be found. If it cannot, the aircraft goes to its alternative target. For air-to-ground missions, the target must be acquired by a weapon system. User-input tables in **agwpmin.dat** include the minimum ceiling and visibility for various combinations of aircraft and munition types. If either the *actual* ceiling or visibility is less than the minimum for the weapons on the attacking aircraft, no weapons can be used and the target is treated as not found.

An aircraft-weapon pair's ability to acquire a target is based on input tables in **tgtacq.dat** that provide probabilities of target acquisition in terms of aircraft type, air munition type, day or night, and weather band. The probability of acquisition, along with a perception level derived from reconnaissance flights, is used to compute the number of weapons that will be delivered. The probability of target acquisition then is a function of the aircraft-weapon combination; weather provided in the data file **weather.dat**; perception level, provided in the data file **perception.dat** as a percentage of the intelligence knowledge of the enemy by zone-sector; and target acquisition class, specified in data file **stdtgt.dat**. (A perception level, which is not a function of weather, is a value between 0 and 100 that is applied to all targets within a zone and sector.) Note that target acquisition is not part of the planning process.

In high resolution modeling the weather or weather *forecasts* at any target is that of the weather station assigned that target. The nearest weather station is assigned to fixed targets and to grid squares as part of the initialization process. If a moving target is in a grid square, the weather station for that square is used. If a moving target is not in a grid square, the nearest weather station is found and its weather is used. When the resolution is low, the weather is always good.

Thus, a flight group's ability to locate a target is based upon the *actual* weather and the current perception level in the target's zone-sector. When a flight group arrives at the perceived target location, THUNDER checks the *actual* local weather. The weather minimum and maximum error distance is defined for each aircraft and target type in data file **typeac.dat**. If either the current ceiling or visibility (from **weather.dat**) is less than the minimum for the aircraft-target pair, or if the flight group has no munitions that may be used under current ceiling and visibility, the target is not found and a secondary target is attacked. Accordingly, the initial weather effect on the attack is either to go or not to go to the primary target.

After a target area has been found by the flight, the target must be acquired by a weapon system. An aircraft-weapon pair's ability to acquire a target element is based on ceiling and visibility, day-night, zone-sector perception, and target type (all of which are specified in data file **tgtacq.dat**). The acquisition probabilities are used to calculate the number of each flight's munitions that will be delivered. All munitions that do not have appropriate ceiling and visibility to be delivered are removed from consideration. The weather effect then would be to preclude specific target elements from being attacked because that target element cannot be acquired. The probability of target acquisition (from data file **dwta.prob.target.acquisition**) is adjusted by the current zone-sector perception level to determine the probability that each of the remaining munitions will be delivered.

2.5.2 GROUND TARGET ACQUISITION AND KILL

The weather's greatest influence on the air war simulated by THUNDER is on the success of attack of ground targets. To understand how weather affects success, it is necessary to consider the different types of targets and their acquisition, discrimination, and kill.

THUNDER specifies all targets in terms of a generic set of data structures that define targetable elements within a target and their characteristics. A target group is a set of standard targets located in the same area at a target. Members of a target group can suffer collateral damage when a member of their group is attacked by an area effects weapon. Target group members have characteristics that are described by target definitions; moving targets have multiple definitions. The standard target, which consists of a number of elements and a target radius, is the basic element used to build composite targets. Each standard target also belongs to target acquisition and target discrimination classes, which are used in the assessment of the target. The standard target methodology for defining composite targets corresponds to the Joint Munitions Effectiveness Manual (JMEM) of targets. The data file **stdtgt.dat** specifies target acquisition and discrimination classes, and classifies and lists all standard targets.

Target discrimination, an aircraft's ability to find the most desirable targets in a mixed target array, is a function of the same variables as target acquisition. Similar to the probability of target acquisition, a probability of target discrimination is defined for each weather band, day-night, aircraft-munition, and target class (all of which are specified in data file **tgtacq.dat**).

Once the aircraft has found the target and its weapons system has acquired and discriminated a specific target element, THUNDER then uses the *actual* ceiling and visibility (from **weather.dat**) at the target to find the probability of kill (P_k), which is contained in the data file **airgrdpk.dat**, against the target. (Recall that **airgrdpk.dat** also was used to plan the mission and arm the aircraft.) The P_k is a function of day-night, weather band at the target, aircraft-munition pair, and standard target type. Given that a live target element is hit, THUNDER then makes a random draw against the P_k to determine if the target element is destroyed.

2.6 SUMMARY

At high resolution, THUNDER can simulate some of the effects of weather on an air war, especially air-to-ground attack missions, both in their planning and execution phases. THUNDER accounts for only two specific weather factors, ceiling and visibility, both having effects on several aspects of the simulated air war. Through user-input data files described in Appendix A, ceiling and visibility affects to some degree airbase operations, weapon effectiveness, air-to-ground target acquisition, and target discrimination and kill.

Weather *forecasts* affect only mission planning and aircraft arming, not target acquisition and attack. On the other hand, *actual* weather can have an important effect on the outcome of sorties. Missions are planned for airbases whose *forecast* of ceiling and visibility is above base takeoff minimums, that is, a go/no go decision. Consequently, an incorrect *forecast* that airbase weather will be above minimums at launch time would ground aircraft that were planned for attack. Similarly, an incorrect *forecast* that airbase weather would be below minimums at launch time would needlessly remove aircraft based there from the planned attack. Missions and aircraft arming configurations are selected to maximize weapon system effectiveness. The expected effectiveness is a function of *predicted* weather at the target as well as the specific target and type of munitions.

The *actual* weather at an airbase affects aircraft takeoff or landing if the ceiling or visibility is below the base minimums. A flight proceeds to its planned target regardless of the *predicted* weather. The *actual* weather at the target, however, affects the capability of a ground attack aircraft to find the target. When the aircraft finds the target, weather there affects the capability of the weapon system to acquire the target. If

the weather is below the minimums of the attacking aircraft weapon system's ability to acquire the target, none of the weapons are used. The target, then, is not found and the aircraft proceeds to an alternate target. If the weather is above those minimums, THUNDER uses lookup tables to assign probabilities to acquire the target, to discriminate among the target elements, and to kill them.

Table 1 summarizes the flow (from top to bottom) of weather-related data input during the execution of THUNDER at high resolution.

Table 1. THUNDER's Use of Weather-Related Data Input Files

Phase of THUNDER's Air War	User-Input Data File Name	Weather-Related Function
Initial Planning	**control.dat**	Selects low or high resolution.
Planning and Execution	**weather.dat**	Provides weather bands of ceiling and visibility, weather stations and locations, day segments, *actual* and *forecast* ceilings and visibilities.
Mission Planning	**weather.dat** **stdtgt.dat** **airgrdpk.dat**	Uses *forecasts* from weather.dat to select aircraft-weapon system configuration for standard targets listed in **stdtgt.dat**.
Mission Execution	**weather.dat** **stdtgt.dat** **typeac.dat**	Determines if target can be detected based on maximum range and minimum ceiling-visibility at the target, based on *actual* weather from **weather.dat**.
	weather.dat **stdtgt.dat** **agwpnmin.dat**	Determines if target can be attacked based on weather capabilities (minimum ceiling and visibility) of the aircraft-weapon system configuration.
	weather.dat **stdtgt.dat** **tgtacq.dat**	Determines probabilities of target acquisition and discrimination based on *actual* ceiling and visibility at the target and lookup tables of probability.
	weather.dat **stdtgt.dat** **airgrdpk.dat**	Determines probability of killing the target based on *actual* ceiling and visibility at the target and look-up tables of probability.

3. EXTENDED AIR DEFENSE SIMULATION (Reference 3)

EADSIM is an analytical model of air and missile warfare used for scenarios ranging from few-on-few to many-on-many. It is a powerful analytical tool for evaluating the effectiveness of various command, control, communications, and intelligence (C^3I), theater missile defense, and air defense architectures. EADSIM is also used to evaluate weapon systems in the full context of an environment of sensors, command and control (C^2) centers, communication systems, platform dynamics, and weapon performance. It is unique in that each platform (such as fighter aircraft) is individually modeled, as is the interaction among the platforms. EADSIM models several general areas: air defense, offensive air operations, attack operations, multi-stage ballistic missiles, air breathers, sensors (radar, IR, launch detection, and radar launch warning), jammers, satellites, early warning, generic noncombatants, communications, electronic warfare, terrain, weaponry, and other areas of interest.

3.1 MODELED PROCESSES

The EADSIM model consists of a number of processes and process applications performing three basic functions: simulation setup, execution of a scenario, and postprocessing and analysis. In full analytic configuration, there are four processes: C^3I, flight processing, detection, and propagation. All processes in EADSIM rely on data files for storage and retrieval of definitions of everything in a given scenario. The data files reflect the levels of abstraction used in the scenario. The scenario file contains the paths of all of the data files to be used, e.g., areas of interest, elements, laydowns, and others, as well as atmospheric transmittance and radiance. (Atmospheric transmittance and radiance are used only by the detection process and are not part of C^3I.) A specific platform used in a scenario is based on a specific system. A system is a collection of what basic elements are used, that is, communication devices, jammers, protocols, sensors and weapons, with a guideline to using the elements: a ruleset.

3.2 THE COMMAND, CONTROL, COMMUNICATIONS, AND INTELLIGENCE PROCESS

C^3I is the core process of the EADSIM, performing all the battle management functions for each participant in the scenario while that platform is active. These functions include the allocation of weapons against targets, both on the ground and in the air. There are four general types of combat engagements modeled; however, **none are affected by weather**. The type most likely needing to account for weather is the air-to-ground engagement, which provides the capabilities for a participant to search and identify its targets, as determined from the initial scenario data, and then attempt to destroy those targets. By using data files (e.g., the laydown file, which includes information on system types, targets and sensors, and the ruleset elements file) the user establishes a scenario and all parameters associated with that scenario. The C^3I

process determines the interaction between participants in a scenario. While many factors influence the activities of a platform in the scenario, the ruleset under which the platform is operating determines the actions of the platform.

3.3 GROUND ATTACK

The modeling supports free-fall bombs, anti-radiation missiles, a warhead, and air-to-surface missiles. The probability of a target being killed is unaffected by weather but is set by the user, either as a single value or defined in a table, for each type of weapon against a target. The combat-ready flights of aircraft will launch from any airbase to which the ground attack commander has a communication link. The airbase ruleset, which controls an airfield, aircraft flights, and a commander, excludes consideration of weather from having an effect on the launching of aircraft from or their returning to an airbase.

There are several phases to a modeled offensive ground attack by bombers (or fighter-bombers) that launch weapons on surface targets. These phases include selecting the target, engaging the target, launching the weapon, and evaluating the results of the attack. An air-to-ground attacker (airplanes, helicopters, cruise missiles, and tactical air-to-surface missiles) has similar phases but with expanded rulesets. The target selection phase includes weapon selection based on P_k (weather is not considered) unless the user has specified a weapon. Within these phases and rulesets, it is possible to model the use of "*smart*" weapon systems, including their sensors that detect targets.

3.4 SUMMARY

Weather plays no role in EADSIM. The atmosphere, however, is represented by constants in tables to account for the natural environment's effects on energy transmission and radiance in target detection. These tables are derived from Lowtran 7, 1962 Standard Atmospheric Data, and the 1976 U.S. Standard geographical-seasonal model atmosphere.

4. WEATHER EFFECTS ON ELECTRO-OPTICAL SENSORS (References 4, 5, and 6)

As vividly demonstrated during the Persian Gulf War, electro-optical (EO) weapon systems are important tools used by the modern war fighter. There are, however, significant weather effects on the EO sensors used on air-to-ground weapon systems, that is, precision guided munitions (PGM) and target acquisition systems (TAS). These effects and relevant background are reviewed briefly.

Sensors are the basic building blocks around which EO weapon systems are built. The signal that activates a sensor may come from one of three sources: energy reflected from the target, energy emitted from the target, and/or energy emitted or reflected from the target's immediate environment. The propagation of this electromagnetic energy is affected by the weather.

4.1 ELECTROMAGNETIC ENERGY PROPAGATION

Electro-optical energy occupies a small part of the electromagnetic spectrum where wavelengths are between 0.1 cm and 10^{-6} cm (the frequency band covers 300 GHz to 3×10^{7} GHz) and includes the submillimeter, infrared, visible, and ultraviolet bands. This spectrum is characterized by a high information bandwidth, very high spatial resolution, and highly variable absorption and attenuation by the atmosphere itself, as well as weather (e.g., fog, rain, clouds), dust, and smoke.

4.2 TARGET ACQUISITION

The performance of EO systems is critically dependent on how electromagnetic radiation interacts with the atmosphere, the target, and the target's background. This performance, or ability of a sensor to detect a target, is a function of the apparent contrast, the contrast between a target and its background at some range that accounts for the effects of the intervening atmosphere. Radiation within the EO band interacts with the atmosphere mostly as a function of well-known physical processes such as reflection, scattering, absorption (taken together, scattering and absorption are extinction), and emission. Atmospheric transmission of energy is affected by atmospheric gases, especially water vapor, and rain, fog, snow, and clouds (line of sight).

The EO weapon system must pick out the target from its background clutter, that is, it must recognize the target's unique characteristics—its signature. This process is called target acquisition. Adverse environments degrade the operation of a sensor by interfering with its ability to "see" the target; hence the sensor cannot recognize the target's signature of energy propagation variations. To minimize these effects, sensors may employ different parts of the electromagnetic spectrum, for example, visible radiation may not penetrate fog but millimeter wave radiation may.

For a passive sensor, such as an infrared (IR), to distinguish between a target and its background, a sufficient contrast must exist. In the case of an IR sensor, for example, there must be an effective temperature difference between the target and its surroundings. Accordingly, IR sensors require cloud-free paths from sensor to target. Moreover, the weather affects sensor performance (detection) more strongly as the usable wavelength of the sensors decreases. For example, haze and precipitation especially degrade near- and

middle-IR systems, and absolute humidity and precipitation severely degrade far-IR systems. Similarly, an optical sensor reacts to reflected (visible) light differences between an object target and its background. Visible systems cannot "see" through clouds or fog, and the atmospheric extinction of energy through rain, haze, snow, for example, limits their use. Therefore, although optical and IR sensors are high precision sensors, they may be unusable in rain, snow, fog, and clouds.

4.3 WEATHER EFFECTS

Weather effects on targets and their background, therefore, can reduce the effectiveness of EO weapon systems. Cloud ceilings can either block all visible and IR radiation between a sensor and target or subdue thermal clutter by blocking solar insolation that otherwise would heat objects in the target scene. Low visibility, which can be caused by several weather factors (such as rain, snow, fog, haze, smoke, or dust), obviously degrades the performance of optical sensors by smearing target signatures. Recent precipitation can cool all objects within a target scene, wiping out temperature contrasts between the target and its background. Table 5 of Reference 4 provides a detailed discussion of EO sensor weather effects; those not involving terrain are summarized in Table 2 below.

Table 2. Degree of Adverse Effect of Weather on EO Sensor Performance

Weather Factor	Visible Radiation	IR Radiation	Millimeter Wave Radiation
Precipitation	Strong	Strong	Strong only for heavy
High Absolute Humidity	None	Weak	None
Very High Relative Humidity	Strong	Strong	None
Temperature	None	Weak-Strong	Weak
Sky Obscuration	Weak-Strong	Weak-Strong	None
Clear Sky	Weak	Strong in day	None
Dry Aerosol	Mostly Weak	Weak	None
Moist Aerosol	Strong	Strong	Weak

4.4 SUMMARY

By interfering with the propagation of electromagnetic energy between a sensor and a target, the weather can adversely affect the performance of electro-optical weapon systems. Moreover, weather effects can blur the contrast between a target and its background, making it difficult or impossible for the sensor to discriminate between the two. Since these EO weapon systems are so important to modern warfare, their realistic role needs to be played in military simulations, especially now that operational forecasts are specifically tailored to their employment.

5. SUMMARY OF FINDINGS AND CONCLUSIONS

Of the two models reviewed for this report, the discussion below focuses on THUNDER because EADSIM does not account for weather effects directly. Where EADSIM accounts implicitly for the effects of weather, these effects are treated without rigor (e.g., electromagnetic energy transmission factors and radiance data for target detection are taken from a look-up table of constants). While both models prescribe values of probability of target acquisition, discrimination, and kill by weapon system and target, only THUNDER's probabilities are an explicit function of weather.

The findings and conclusions on how THUNDER and EADSIM incorporate weather effects are briefly summarized in this section. Section 6 concludes the report with recommendations for research and development.

5.1 WEATHER EFFECTS IN THUNDER AND EADSIM

These two important models for simulating air warfare were reviewed to determine how rigorously they account for the effects of the natural environment (i.e., weather effects). With modern air warfare's recent focus on the use of electro-optical weapon systems, the focus of this report is on the simulation of the weather's effect on air-to-ground missions using the PGMs or TASs.

THUNDER accounts for weather effects in terms of *actual* and *forecast* ceilings and visibility at predefined locations. The *forecasts* affect mission planning and aircraft arming (but not mission execution) though look-up tables of probability of target acquisition, discrimination, and kill. Missions are planned only for airbases whose ceiling-visibility is *forecast* to be above takeoff minimums. The *actual* weather at a target affects an attack; if the ceiling-visibility is below the minimums of the aircraft-munition's capability to acquire the target, the weapon is not used and the aircraft flies to its next target.

EADSIM does not account for weather on air attacks or any other combat engagements. In air-to-ground attacks, however, the probability of a target being killed is set by the user and, therefore, could implicitly account for the weather effects.

5.2 WEATHER AND WEATHER EFFECTS DATA INPUT TO THUNDER

THUNDER's approach to simulating the effects of weather on the air-to-ground attack appears to be sufficient to allow the weather to influence logically the outcome of these attacks. The effectiveness of this approach is unclear, though, because the validity of the values assigned to the probability sets of target acquisition, discrimination, and kill could not be determined from the references available for this literature review.

The critical component in the simulation of weather effects on the air war is found in tables of these probability sets. **If these probabilities fail to reflect reality, then so will the results of the simulated air-to-ground attacks**—one of the primary purposes for using THUNDER. It is neither possible to determine from the reviewed documents that the probability sets of target acquisition, discrimination, and kill have been validated, verified, and/or accredited; nor is it possible to access whether these sets were rigorously developed (i.e., based on physical models and empirical data) or at least tailored for EO weapon systems. Also, THUNDER's sensitivity to changes made to these probability sets, *forecast* weather, and *actual* weather could not be determined from the available references.

The validity of the values in the probability sets that are a function of weather should be reviewed and verified. The air-to-ground air munitions versus the target **(airgrdpk.dat)** data file includes air munition effectiveness for each munition on each aircraft against a standard target for each weather band. The ground target acquisition and discrimination **(tgtacq.dat)** data file groups each valid air munition-aircraft combination into target acquisition and discrimination categories, which are used to define the probability of target acquisition and discrimination for each weather band for both day and night.

Some of the values used in the weather **(weather.dat)** data file need to be studied for meteorological consistency and for use in simulating an air war. This file includes user-defined weather station names; weather bands; scripted *actual* ceiling and visibility by times, day segments, and weather station; and scripted *forecast* ceiling and visibility. The documentation provides no evidence that the weather scenarios were carefully tailored for the purpose of specific THUNDER executions or that there was more than minimal interaction between the user and the provider of weather data.

The above discussion in this subsection is *not* intended to suggest that THUNDER's approach to the incorporation of weather effects is weak, only that the foundation of the approach should be checked to ensure that it is solid. All the verification or validation of data input described requires no execution of THUNDER, although the testing of THUNDER's use of weather and weather-related data would be useful and informative.

5.3 SENSITIVITY ANALYSIS OF THUNDER

Regardless of the validity of the data input, however, a sensitivity analysis is needed to determine the effect of changes in the weather data and the probabilities of target acquisition, discrimination, and kill tables on the simulation. Obviously, the results of THUNDER's air attacks must be sensitive to these changes, or the goodness of the weather effects data will not matter. Moreover, the conclusion that a sensitivity analysis is needed can also be drawn from Reference 7, a study conducted by the Air Force Studies and Analysis Agency for HQ USAF/XOW to determine the value of improved weather forecasting to warfighters.

5.4 WEATHER EFFECTS ON ELECTRO-OPTICAL WEAPON SYSTEMS

The only weather factors in THUNDER are ceiling and visibility; hence, many other weather factors (e.g., temperature and precipitation) that affect visual and IR-sensor performance are unaccounted for. Given that a sensitivity analysis could provide a better understanding of how weather affects the air-to-ground attack war, it may be possible to modify the probability tables in **tgtacq.dat** and **airgrdpk.dat** to account implicitly for most of the weather factors that affect visible and IR-sensor performance. These modifications to the probability tables could be based on physical models and the results of operational forecasts for employment of EO weapon systems as well as their correlation to ceiling and visibility. For example, results from the Electro-Optical Tactical Decision Aids (Reference 5) could be incorporated in the form of look-up tables, which would have to be developed for use in THUNDER.

The improved probabilities (specifically, the probability tables in **tgtacq.dat** and **airgrdpk.dat**) represent a high potential payoff at low cost. The modifications could account better for weather effects on EO weapon systems without requiring development of new software modules and their integration into THUNDER followed by extensive testing.

6. RECOMMENDATIONS

Several recommendations for improving the use of weather and weather effects in THUNDER and EADSIM are discussed and supported below in order of desired implementation. A sensitivity analysis of the effect THUNDER's weather input tables have on air-to-ground attacks is needed to provide a baseline understanding of how these tables affect the simulated air war. Other approaches avoid reliance on data input look-up tables, which could require continual updating.

6.1 VERIFICATION OF VALUES USED IN WEATHER-RELATED DATA INPUT FILES

All input weather and weather effects data need to be validated, especially the validity of the values in the probability sets that are a function of weather need to be established. These probabilities should be established from physics-based models and algorithms, as well as applications of numerical analysis techniques of fitting empirical data. Although not formally reviewed as part of this study, considerable work has already been performed on developing algorithms for probabilities of detecting and killing targets. The use THUNDER made of the results of this work cannot be determined from the documents available during the brief review reported here. If THUNDER's probability sets are not based on sound models (or algorithms), then the probability sets need to be updated. It could be possible to develop probability algorithms that are a function of weather (as well as other relevant factors) for direct use in THUNDER.

6.2 SENSITIVITY ANALYSES OF THUNDER

The proposed sensitivity analysis is uncomplicated. *Forecasts* will be assumed to be perfect (a typical scenario in THUNDER); hence, the scripted *forecasts* and *actual* weather in **weather.dat** will be identical. The tables whose sensitivity will be analyzed are in the **tgtacq.dat** (probability of target acquisition and discrimination) and **airgrdpk.dat** (probability of kill) data files. A war will be simulated several times by varying these three probability sets to quantify and qualify the effects these probabilities have on THUNDER's measures of effectiveness and measures of outcome (Reference 1).

Additional sensitivity analyses would be used to determine how other changes in weather affect the simulated war. For example, varying the length of the time segments would allow for short-term weather changes to affect the success of target attacks. Perhaps more interesting would be an analysis of the effect of weather *forecasts* "busts," an analysis that might suggest better ways to play *forecasts* in THUNDER. A followup sensitivity analysis will point out the effectiveness of enhancements to improve the simulation of those portions of the air war that are affected by the weather, in particular the air-to-ground attack. The

results of the analysis should yield findings that will lead the way toward developing further improvements in THUNDER and suggest improvements to EADSIM.

If the resulting simulations are sensitive to these induced weather effects on ground attack and airbase operations, then improvements similar to those proposed above for THUNDER could be implemented in EADSIM too. EADSIM, however, will require the addition of a module and code modifications; in contrast THUNDER will require that improvements be made to values in data input tables.

6.3 OTHER APPROACHES

New modules could be added to THUNDER to account explicitly for the effects of the environment on the propagation of electromagnetic energy, rather than implicitly through probability tables. These modules would eliminate the need for look-up tables of probability, completely changing the way THUNDER now accounts for weather effects. For example, FASTPROP (References 8, 9, and 10), which developed an atmospheric server in the context of a distributed interactive simulation exercise (References 11 and 12), was demonstrated as a client serving EADSIM. FASTPROP, which requires meteorological data input, **explicitly** provides effects of realistic weather (including clouds and rain) on the propagation of electromagnetic energy from microwave through visible wavelengths. Weather scenes are generated from HEFeS (Hierarchical Environmental Feature Simulator), which was developed recently at PL/GPAA (Reference 10). Perhaps more useful to THUNDER is another PL/GPAA-developed product, CFLOSA (cloud-free line-of-sight aloft), which explicitly provides the probability of cloud-free line-of-sight as seen by the human eye.

Given the anticipated value of the above improvements to THUNDER and EADSIM, the next step would be the explicit inclusion of other weather factors whose effects are know to affect modern operational warfare. For example, winds have blown smoke over targets and obscured them, fresh snow on the ground may eliminate the visible contrast between a target and its background, and rainfall may cool "hot" targets so that IR images blur.

6.4 SUMMARY OF RECOMMENDATIONS

THUNDER's approach to accounting for the effects of weather appears to be meaningful; nevertheless, the approach should be verified and confirmed. The following list of tasks would accomplish this purpose.

- Verification of the validity of weather-related data input to THUNDER.
- Performance of sensitivity analyses of THUNDER's data input tables of (1) minimum ceiling or visibility allowed for valid air-to-ground munition-aircraft combinations, (2) probability of

target acquisition, discrimination, and kill; (3) weather forecasts and observations; and (4) time segments.

- Improvement of the probability models (or probability sets for data input tables) for THUNDER to account explicitly (implicitly) for environmental effects on EO weapon systems.
- Incorporation of modules such as CFLOSA into THUNDER to provide information explicitly on target acquisition. Consideration should be given to the use of modules, such as FASTPROP, that would require extensive meteorological data.
- Implementation of similar concepts in EADSIM.

REFERENCES

1. THUNDER Analyst's Manual, Version 6.1, May 1994, USAF Air Force Studies and Analysis Agency.
2. THUNDER 6.3 Introductory Course, August 14–19, 1995.
3. Extended Air Defense Simulation (EADSIM) Methodology Manual, Version 4.00, 30 March 1994.
4. Air Weather Service Technical Note 87/003, (AWS/TN-87/003), Weather Sensitivities of Electro-OPTICAL Weapon Systems, December 1987.
5. Electro-Optical Tactical Decision Aid (EOTDA) User's Manual, Volume 1, Version 3, January 1993.
6. Introduction to Precision Guided Munitions, A handbook providing tutorial information and data on precision guided munitions (PGM), Vol. 1: Tutorial, May 1983, U.S. Army Command, Attn: DRSMI-RN, Redstone Arsenal, AL 35989.
7. Weather Forecast Accuracy Requirements Study, Air Force Studies and Analysis Agency/SAG for AF/XOW, August 1995.
8. A DIS Architecture for the FASTPROP Atmospheric Environmental Server, E. Lazarus et.al., presented at the 13th DIS Workshop, October 1995.
9. Implementing Realistic Weather Effects on Line-of-Sight Propagation for Constructive Simulations, C. Lamar et. al., 12th DIS Workshop, March 1995.
10. Introduction to HEFeS (Hierarchical Environmental Feature Simulator), A. Boehm, PL-TR-94-2012, Phillips Laboratory Paper, Hanscom AFB, MA, 1994, ADA283143.
11. E2DIS Environmental Architecture Design Concepts (undated briefing by SPARTA).
12. E2dis Environmental Representations Technical Working Group (ERTWG), 28 March 1996, briefing by Dr. Harry Heckathorn, NRL.

APPENDIX A

WEATHER-RELATED DATA INPUT TO THUNDER

There are no weather-related data inputs for EADSIM; however, THUNDER is designed so that all nontrivial data are completely separate from the model. Model data are stored in a database, whose inputs are controlled with formatted data files. Users can change the files containing information from the database, or they can create their own data files by following the layout in THUNDER, Appendix D, Input File Layouts, Version 6.1, November 1993.

The layout of several data files that either reference weather data or contain weather information is taken from THUNDER, Appendix D, and discussed below. Although these files are written in a programming language called *SIMSCRIPT* II.5, which is a structured English style (similar to pseudo code) that can be self-documenting, explanatory comments are provided.

A.1 CONTROLS DATA FILE (control.dat) LAYOUT

```
CONTROLS
    ...
    COMPUTATIONAL.RESOLUTION.LEVELS (LOW, HIGH)
        ...
        WEATHER        HIGH
        ...
    ...
    DATA.REPORTS.CONTROLS
        ...
        WEATHER.STATIONS
    ...

END.CONTROLS
```

The data file contains two weather-related components. When high resolution is selected, THUNDER will amount for weather effects. A list of the weather stations will be printed in reports.

A.2 AIR-TO-GROUND VS. TARGET EFFECTIVENESS DATA FILE (airgrdpk.dat) LAYOUT

```
AIR.TO.GRD.PKS

BLUE.PK.MULTIPLIER (DEC)      1.0      RED.PK.MULTIPLIER (DEC)      1.0

    BOMBER.IDS
        BLUE......ID...........TYPE.AIRCRAFT.MUNITION.......TYPE.AIR.CRAFT
                10010    105                              1001  1002  1004          END
                10020    106                              1001  1002                END
                ...
        RED......ID...........TYPE.AIRCRAFT.MUNITION.......TYPE.AIR.CRAFT
                20010    204                              2001  2002  2003  2004    END
                ...
    END.BOMBER.IDS

    BOMBER.ID.VS.STANDARD.TARGET.PKS.BY.WEATHER.BAND
        WEATHER.BAND.1
        BLUE.BOMBER.ID              STANDARD TARGETS
                10001  10002  10003  10004  10005  10006  10007  10008  10009  10010
                10101  10102  10103  10201  10202  10301  10302  10303  10401  10402

        10010    .000   .000   .000   .000   .000   .000   .000   .000   .000   .000
                 .000   .000   .000   .000   .000   .000   .000   .000   .000   .000

        10020    .300   .250   .300   .400   .400   .400   .250   .400   .300   .400
                 .450   .450   .050   .150   .250   .250   .150   .150   .150   .250
        ...

    WEATHER.BAND.2
    ...
    END.BOMBER.ID.VS.STANDARD.TARGET.PKS.BY.WEATHER.BAND

END.AIR.TO.GRD.PKS
```

The data labels are somewhat self-explanatory. First, a multiplication factor is provided to modify all probabilities of kill in this file, and bombers (from the blue and red sides) are provided with a user-assigned ID. Each bomber ID is associated with specific types of air munitions to be delivered by specific types of aircraft. Next, for each bomber ID are the probabilities of killing specified standard targets. For each weather band the user inputs the standard target identification text header associated with the assigned bomber IDs and the table of P_k (probability of kill) against the corresponding standard targets. These are input in the same order as the standard targets created in the standard target data file.

In the above example, the probabilities of kill are unmodified because the multiplier is 1.0. For weather band 1, bomber ID 10010 has a P_k of zero for air munition type 105 on aircraft types 1001, 1002, and 1004 against the standard target list 10001–10010, 10101, 10102, ...; bomber ID 10020 has a P_k of 0.30 for air munition type 106 on aircraft types 1001 and 1002 against standard target 10001, ...

A.3 TARGET ACQUISITION DATA FILE (tgtacq.dat) LAYOUT

```
GROUND.TARGET.ACQUISITION
NUMBER.OF.ACQUISITIONS.IDS          3
BEGIN.ACQ.IDS
    10001
        BEGIN.AIRCRAFT
                1001   1002   1004   2001   2002   2003   2004
        END.AIRCRAFT
        BEGIN.TYPE.AIR.MUNITION
                 105    109    110    204    209    210
                 111    112    211
        END.TYPE.AIR.MUNITION

    10002
        BEGIN.AIRCRAFT
                1001   1002   1004   2001   2002
        END.AIRCRAFT
        BEGIN.TYPE.AIR.MUNITION
                 106    113    205
        END.TYPE.AIR.MUNITION

    10003
        BEGIN.AIRCRAFT
                1004
        END.AIRCRAFT
        BEGIN.TYPE.AIR.MUNITION
                 114
        END.TYPE.AIR.MUNITION
END.ACQ.IDS
```

The acq.id is the unique ID of a aircraft-air munition acquisition pair; tgt.acq.class is the target acquisition class (e.g., fixed or mobile targets). In this example, there are three ground target acquisitions, identified as 10001, 10002, and 10003, that are aircraft-air munition acquisition pairs. Acquisition ID 10001 is associated with seven aircraft (1001, 1002, 1004, 2001, 2002, 2003, and 2004) and nine types of air munitions (105, 109, 110, 204, 209, 210, 111, 112, and 211). Similarly, Acquisition ID 10002 is associated with five aircraft (1001, 1002, 1004, 2001, and 2002) and three types of air munitions (106, 113, and 205). Finally, Acquisition ID 10003 is associated with one aircraft (1004) and one type of air munitions (114).

Target Acquisition Data File layout (continued)

PROBABILITY.OF.TARGET.ACQUISITION

ACQ.ID...TGT.ACQ.CLASS.......PROBABILITY.OF.TARGET.ACQUISITION.BY.WEATHER.BAND

10001	10001	DAY	0.20	0.40	0.50	0.60	0.80	0.80
		NIGHT	0.10	0.30	0.40	0.50	0.70	0.70
10001	10002	DAY	0.10	0.30	0.40	0.50	0.70	0.70
		NIGHT	0.05	0.25	0.35	0.45	0.65	0.65
10002	10001	DAY	0.20	0.40	0.50	0.60	0.80	0.80
		NIGHT	0.20	0.40	0.50	0.60	0.80	0.80
10002	10002	DAY	0.10	0.30	0.40	0.50	0.70	0.70
		NIGHT	0.10	0.30	0.40	0.50	0.70	0.70
10003	10001	DAY	0.80	0.80	0.80	0.80	0.80	0.80
		NIGHT	0.80	0.80	0.80	0.80	0.80	0.80
10003	10002	DAY	0.80	0.80	0.80	0.80	0.80	0.80
		NIGHT	0.80	0.80	0.80	0.80	0.80	0.80

END.PROBABILITY.OF.TARGET.ACQUISITION

The probability.of.target.acquisition.by.weather.band is the probability that the target will be acquired for each weather band. Above, the ground target acquisition (aircraft-air munition pair) with IDs 10001, 10002, and 10003 have two target acquisition classes, 10001 and 10002. Each of these ID classes is associated with a probability, ordered by day-night and the six weather bands, that the target will be acquired. For example, ground target acquisition ID 10002 has both daylight and night target acquisition probabilities of 0.20, 0.40, 0.50, 0.60, 0.80, and 0.80 for target acquisition class 10001 for weather bands 1, 2, 3, 4, 5, and 6, respectively.

Target Acquisition Data File layout (continued)

```
NUMBER.OF.DISCRIMINATION.IDS        2

BEGIN.DSC.IDS
        10001
            BEGIN.AIRCRAFT
                1002   1004   2001   2004   2003
            END.AIRCRAFT
            BEGIN.TYPE.AIR.MUNITION
                105 106 109 110 204 205 209 210
                111 112 211 113 114
            END.TYPE.AIR.MUNITION
        10002
            BEGIN.AIRCRAFT
                1001   2002
            END.AIRCRAFT
            BEGIN.TYPE.AIR.MUNITION
                105 106 109 110 204 205 209 210
                111 112 211
            END.TYPE.AIR.MUNITION
END.DSC.IDS
```

The dsc.id is the target discrimination class and tgt.dsc.class is the discrimination class for the unique target-discrimination pair. The layout of this section of the file is similar to the section on ground.target.acquisition discussed. There are two discrimination IDs, 10001 and 10002, that refer to a unique aircraft-air munition discrimination pair. Each ID is associated with two target discrimination classes, 10001 and 10002. Discrimination ID 10001 is associated with five aircraft (1002, 1004, 2001, 2004, and 2003) and 13 types of air munitions (105, 106, 109, 110, 204, 205, 209, 210, 111, 112, 211, 113, and 114). Similarly, discrimination ID 10002 is associated with two aircraft (1001 and 2002) and 11 types of air munitions (105, 106, 109, 110, 204, 205, 209, 210, 111, 112, and 211).

Target Acquisition Data File layout (continued)

PROBABILITY.OF.TARGET.DISCRIMINATION

DSC.ID...	TGT.DSC.CLASS.......	PROBABILITY.OF.TARGET.DISCRIMINATION.BY.WEATHER.BAND						
10001	10001	DAY	0.40	0.50	0.60	0.80	0.80	0.80
		NIGHT	0.30	0.40	0.50	0.70	0.70	0.70
10001	10002	DAY	0.30	0.40	0.50	0.50	0.50	0.50
		NIGHT	0.20	0.30	0.40	0.40	0.40	0.40
10002	10001	DAY	0.50	0.60	0.70	0.80	0.80	0.80
		NIGHT	0.20	0.30	0.40	0.50	0.50	0.50
10002	10002	DAY	0.40	0.50	0.60	0.70	0.70	0.70
		NIGHT	0.10	0.20	0.30	0.40	0.40	0.40

END.PROBABILITY.OF.TARGET.DISCRIMINATION

END.GROUND.TARGET.ACQUISITION

The probability.of.target.discrimination.by.weather.band is the probability that the target will be detected for each weather band. The above target discrimination IDs 10001 and 10002 have two target acquisition classes, also identified as 10001 and 10002. Each of these ID classes is associated with a probability, ordered by day-night and the six weather bands, that a specific target element will be discriminated from other elements. For example, ground target discrimination ID 10002 has daylight target discrimination probabilities of 0.50, 0.60, 0.70, 0.80, 0.80, and 0.80 for target discrimination class 10001 and weather bands 1, 2, 3, 4, 5, and 6, respectively.

A.4 AIR-TO-GROUND WEAPON MINIMUM DATA FILE (agwpnmin.dat) LAYOUT

```
AIR.GROUND.WEAPON.MINIMUM

    CEILING.UNITS (FEET/METERS/MILES)          FEET
    VISIBILITY.UNITS (FEET/METERS/MILES)       MILES

NUMBER.OF.AG.MINIMUM.IDS    2

    10001
    BEGIN.AIRCRAFT
       1001  1002  1003  2001  2002  2004  2003
    END.AIRCRAFT
    BEGIN.TYPE.MUNITION
       105  106  109  110  204  205  209  210  111  112  113  211
    END.TYPE.MUNITION
    MINIMUM.CEILING (FEET)             400
    MINIMUM VISIBILITY (MILES)         2.5

    10002
    BEGIN.AIRCRAFT
       1004
    END.AIRCRAFT
    BEGIN.TYPE.MUNITION
       105  106  109  110  111  112  113  114
    END.TYPE.MUNITION
    MINIMUM.CEILING (FEET)             0
    MINIMUM VISIBILITY (MILES)         0
END.MIN.IDS

END.AIR.GROUND.WEAPON.MINIMUM
```

This file provides the minimum ceiling and visibility (weather) conditions under which an aircraft-air munition pair can acquire targets and discriminate among target elements. The units of ceiling-visibility are feet-miles. Above, there are two air-ground weapon minimum IDs, 10001 and 10002. Each corresponds to aircraft-munition pairs and a minimum ceiling and visibility. Air-to-ground weapon minimum 10001 is associated with seven aircraft (1001, 1002, 1003, 2001, 2002, 2004, and 2003) and 12 types of air munitions (105, 106, 109, 110, 204, 205, 209, 210, 111, 112, 113, and 211). The weather minimums are a ceiling of 400 ft or a visibility of 2.5 miles. For example, an A-10 has an ID of 1001, an AGM-65 is air munition type 106, and the minimum ceiling-visibility is 400 ft /2.5 miles. Finally, there are no weather minimums for ID 10002 (aircraft 1004 with air munitions 105, 106, 109, 110, 111, 112, 113, and 114) except the seldom observed ceiling on the ground and visibility of zero.

A.5 WEATHER DATA FILE (weather.dat) LAYOUT

weather.801

CEILING.UNITS (FEET/METERS/MILES) FEET

VISIBILITY.UNITS (FEET/METERS/MILES) MILES

NUMBER.OF.WEATHER.BANDS 6

BAND.NUMBER	.....CEILING (FT)	..........VISIBILITY (MILES)
1	500	3
2	1500	3
3	3000	4
4	6000	5
5	12000	5
6	18000	5

END.WEATHER.BANDS

NUMBER.OF.WEATHER.STATIONS 10

...ID	......NAME	...............................LATITUDE	..................LONGITUDE
1001	"NORTH WEST"	52D19.4M-N	8D38.0M-E
1002	"NORTH WEST CENTRAL"	52D14.9M-N	9D47.0M-E
1003	"NORTH CENTRAL"	52D05.7M-N	11D07.9M-E
1004	"NORTH EAST CENTRAL"	51D58.6M-N	11D58.3M-E
1005	"NORTH EAST "	51D51.9M-N	12D40.2M-E
1006	"SOUTH WEST"	51D43.7M-N	8D27.40M-E
1007	"SOUTH WEST CENTRAL"	51D35.2M-N	9D41.1M-E
1008	"SOUTH CENTRAL"	51D24.0M-N	11D00.7M-E
1009	"SOUTH EAST CENTRAL"	51D21.9M-N	11D43.2M-E
1010	"SOUTH EAST"	51D16.5M-N	12D32.4M-E

END.WEATHER.STATIONS

weather.801(continued)

NUMBER.OF.DAY.SEGMENTS 3

...ID......NAME...............................	START.TIME......	END.TIME
1 NIGHT-AM	0.0	6.0
2 DAY	6.0	18.0
3 NIGHT-PM	18.0	24.0

END.DAY.SEGMENTS

BEGIN.STATION.IDS

1001 1002 1003 1004 1005

1006 1007 1008 1009 1010

END.STATION.IDS

Weather.801 is the data label for the weather bands, weather stations, and day segments.

The units for ceiling are feet and for visibility are nautical miles.

There are a total of six weather bands of ceiling and visibility as follows: weather band number 1 has a ceiling of 500 ft and a visibility of 3 miles, weather band number 2 has a ceiling of 1,500 ft and a visibility of 3 miles, weather band number 4 has a ceiling of 3,000 ft and a visibility of 4 miles, weather band number 5 has a ceiling of 12,000 ft and a visibility of 5 miles, and weather band number 6 has a ceiling of 18,000 ft and a visibility of 5 miles. The highest weather band number is used as the argument of any look-up table when THUNDER's resolution is low.

There are 10 weather stations, each with an ID, name, and specified latitude and longitude.

There are three day segments: segment 1, named NIGHT-AM, begins at 0000 and ends at 0600; segment 2, named DAY, begins at 0600 and ends at 1800; segment 3, named NIGHT-PM, begins at 1800 and ends at 2400.

The on-line weather stations are identified in order (i.e., two rows of five columns of stations) of the layout of *actual* and *forecast* ceiling and visibility shown on the following two pages.

Weather Data File (continued)

ACTUAL.WEATHER

		.... FOR.EACH.STATION									
DAY	SEGMENT	CEIL	VIS	CEIL	VIS	CEIL	VIS	CEIL	VIS	CEIL	VIS
1	1	3000	3	18000	5	18000	5	18000	5	18000	5
		8000	4	18000	5	18000	5	18000	5	18000	5
	2	2000	2.5	18000	5	18000	5	18000	5	18000	5
		8000	4	18000	5	18000	5	18000	5	18000	5
	3	2500	3	8000	4	18000	5	18000	5	18000	5
		8000	4	18000	5	18000	5	18000	5	18000	5
2	1	18000	5	3000	3	18000	5	18000	5	18000	5
		18000	5	8000	4	18000	5	18000	5	18000	5
	2	18000	5	2000	2.5	18000	5	18000	5	18000	5
		18000	5	8000	4	18000	5	18000	5	18000	5
	3	18000	5	2500	3	8000	4	18000	5	18000	5
		18000	5	8000	4	18000	5	18000	5	18000	5
3	1	18000	5	18000	5	3000	3	18000	5	18000	5
		18000	5	18000	5	8000	5	18000	5	18000	5
	2	18000	5	18000	5	2000	2.5	18000	5	18000	5
		18000	5	18000	5	8000	5	18000	5	18000	5
	3	18000	5	18000	5	2500	3	8000	4	18000	5
		18000	5	18000	5	8000	4	18000	5	18000	5
4	1	18000	5	18000	5	18000	5	3000	3	18000	5
		18000	5	18000	5	18000	5	3000	3	18000	5
	2	18000	5	18000	5	18000	5	2000	2.5	18000	5
		18000	5	18000	5	18000	5	2000	2.5	18000	5
	3	18000	5	18000	5	18000	5	2500	3	8000	4
		18000	5	18000	5	18000	5	2500	3	8000	4
5	1	18000	5	18000	5	18000	5	18000	5	3000	3
		18000	5	18000	5	18000	5	18000	5	8000	4
	2	18000	5	18000	5	18000	5	18000	5	2000	2.5
		18000	5	18000	5	18000	5	18000	5	8000	4
	3	18000	5	18000	5	18000	5	18000	5	2500	3
		18000	5	18000	5	18000	5	18000	5	8000	4

END.ACTUAL.WEATHER

The prescribed *actual* weather (ceiling and visibility) for each of the 10 stations is given in order of the station.ids by day and day segment. In the case here, on Day 1 during Day Segment 1 Weather Station 1001 has a ceiling of 3,000 ft and a visibility of 3 miles; Weather Stations 1002, 1003, 1004, and 1005 have a ceiling of 18,000 ft and a visibility of 5 miles; Weather Station 1006 has a ceiling of 8,000 ft and a visibility of 4 miles; and Weather Stations 1007, 1008, 1009, and 1010 have a ceiling of 18,000 ft and a visibility of 5 miles.

Weather Data File (continued)

FORECAST.WEATHER

.... FOR.EACH.STATION...

DAY	SEGMENT	CEIL	VIS	CEIL	VIS	CEIL	VIS	CEIL	VIS	CEIL	VIS
1	1	3000	3	18000	5	18000	5	18000	5	18000	5
		8000	4	18000	5	18000	5	18000	5	18000	5
	2	2000	2.5	18000	5	18000	5	18000	5	18000	5
		8000	4	18000	5	18000	5	18000	5	18000	5
	3	2500	3	8000	4	18000	5	18000	5	18000	5
		8000	4	18000	5	18000	5	18000	5	18000	5
2	1	18000	5	3000	3	18000	5	18000	5	18000	5
		18000	5	8000	4	18000	5	18000	5	18000	5
	2	18000	5	2000	2.5	18000	5	18000	5	18000	5
		18000	5	8000	4	18000	5	18000	5	18000	5
	3	18000	5	2500	3	8000	4	18000	5	18000	5
		18000	5	8000	4	18000	5	18000	5	18000	5
3	1	18000	5	18000	5	3000	3	18000	5	18000	5
		18000	5	18000	5	8000	5	18000	5	18000	5
	2	18000	5	18000	5	2000	2.5	18000	5	18000	5
		18000	5	18000	5	8000	5	18000	5	18000	5
	3	18000	5	18000	5	2500	3	8000	4	18000	5
		18000	5	18000	5	8000	4	18000	5	18000	5
4	1	18000	5	18000	5	18000	5	3000	3	18000	5
		18000	5	18000	5	18000	5	3000	3	18000	5
	2	18000	5	18000	5	18000	5	2000	2.5	18000	5
		18000	5	18000	5	18000	5	2000	2.5	18000	5
	3	18000	5	18000	5	18000	5	2500	3	8000	4
		18000	5	18000	5	18000	5	2500	3	8000	4
5	1	18000	5	18000	5	18000	5	18000	5	3000	3
		18000	5	18000	5	18000	5	18000	5	8000	4
	2	18000	5	18000	5	18000	5	18000	5	2000	2.5
		18000	5	18000	5	18000	5	18000	5	8000	4
	3	18000	5	18000	5	18000	5	1800	5	2500	3
		18000	5	18000	5	18000	5	18000	5	8000	4

END.FORECAST.WEATHER

END.WEATHER

The prescribed *forecast* weather for each station is also given in order of station.ids by day and day segment. In this case, on Day 1 during Day Segment 1 Weather Station 1001 has a *forecast* ceiling of 3,000 ft and a visibility of 3 miles; Weather Stations 1002, 1003, 1004, and 1005 have a *forecast* ceiling of 18,000 ft and a visibility of 5 miles; Weather Station 1006 has a *forecast* ceiling of 8,000 ft and a visibility of 4 miles; and Weather Stations 1007, 1008, 1009, and 1010 have a *forecast* ceiling of 18,000 ft and a visibility of 5 miles. Note that the *forecast* is perfect because it is identical to the *actual* weather.

A.6 TYPE AIRCRAFT DATA FILE (typeac.dat) LAYOUT

```
TYPE.AIR.CRAFT
NUMBER.OF.AIRCRAFT.TYPES 11
    1001            "A-10"
        ...
        PERFORMANCE.DATA
            ...
            LANDING.LENGTH (METERS)  MISSION      WEATHER      NIGHT
                                       896          1500         900
            ...
        MISSION.DATA
            ...
            TGT.DETECT.DATA. (METERS) MIN.CEIL    MIN.VIS      MAX.DIST
                "LOG FACILITY"         100          400         10000
                ...                    ...          ...          ...
                ...                    ...          ...          ...
                "STRATEGIC TARGET"     100          400         10000
            ...
        ...
    END.AIRCRAFT
END.TYPE.AIRCRAFT
```

In this example, an A-10 needs a runway length of 896 m to land in clear weather during the day, 1500 m during the day in weather, and 900 m at night. The A-10 needs a minimum ceiling-visibility of 100/400 m to locate the given types (i.e., logistics, facility) of targets. The maximum distance at which the A-10 can detect those targets is 10,000 m.

A.7 SUMMARY

This discussion of THUNDER's weather-related data input files points out how the user completely controls the weather's effect on the air war. Of course, at low resolution the weather is good and, thus, produces no effect whatever. At high resolution, though, both weather *forecasts* and *actual* weather are specified. Moreover, by specifying the probabilities of target acquisition, discrimination, and kill by weapon system and weather, the user explicitly controls weather effects on air-to-ground attacks. These specified probabilities as well as weather *forecasts* and *actual* weather, accordingly, must be carefully chosen.